In vivo Cardiac cine $^{23}$Na MRI in rats

Maurits A. Jansen¹, Urte Kägebein¹, Friedrich Wetterling², Gillian A. Gray¹, and Ian Marshall¹

¹Centre for Cardiovascular Science, University of Edinburgh, Edinburgh, Midlothian, United Kingdom; ²Faculty of Engineering, Trinity College Dublin, Dublin, Leinster, Ireland

Background
Absolute tissue sodium concentration is elevated in myocardial infarction and has been suggested as a biomarker for cell viability [1]. Sodium MRI is challenging due to relatively low $^{23}$Na concentrations in biological tissues, low NMR sensitivity and the short T$_2$ of the $^{23}$Na nucleus. On the other hand, the relatively short longitudinal relaxation time (T$_1$) of the $^{23}$Na nucleus (~30 ms), allows quantitative imaging with short repetition times (TR). Untriggered $^{23}$Na chemical shift imaging (CSI) was previously used for imaging of isolated perfused rat hearts [2]. For imaging of the in vivo heart, however, ECG-triggering is required to minimize image blurring due to cardiac motion, which poses restrictions on TR.

Objectives
To implement and test a new $^{23}$Na chemical shift imaging method for imaging of the in vivo rat heart during several different phases of the cardiac cycle with sufficient spatial resolution.

Methods
Female Sprague-Dawley rats (220-260g, n=6) were scanned in an Agilent 7T DirectDrive MRI scanner. Short-axis ECG-triggered/respiration-gated cine $^1$H MRI was performed using a gradient echo sequence with 128 x 128 matrix, 40 x 40 mm field of view for functional assessment and anatomical reference. 2D acquisition-weighted $^{23}$Na CSI was done using a home-built 30-mm Ø $^{23}$Na surface coil in transceiver mode. ECG-triggered $^{23}$Na images were acquired with a 40 x 40 matrix, 40 x 40 mm field of view and 3.5 mm slice thickness, TR 1 R-R interval (~180 ms) either at only 1 phase during the cardiac cycle (end-diastolic or end-systolic) or up to 6 phases (cine version, effective TR 30 ms) equally distributed over the cardiac cycle. The flip angle was adjusted for maximum signal per unit of time (90° for the conventional CSI and 68° for the cine CSI sequence with 6 phases). The total acquisition time was ~70 min. The CSI data was reconstructed using in-house written software and analysed using jMRUI (http://www.mrui.uab.es/).

Results
Figure 1 shows short-axis $^1$H (left), corresponding $^{23}$Na (middle) and overlay images at end-diastole (top row) and end-systole (bottom row). The myocardium as well as the left and right ventricle of the heart are clearly visible (figure 1). The $^{23}$Na myocardium/blood signal ratio was 0.46 ± 0.05, which is in good agreement with the reported value of 0.45 [3]. Using the cine version of the CSI sequence, several frames of the cardiac cycle could be recorded with reduced TR (~30ms) but similar image quality (myocardium/blood signal ratio: 0.44 ± 0.07 (figure 2)). The SNR of the cine CSI sequence was 38% lower than that of the standard CSI sequence as expected with this combination of TR and flip angle.

Discussion and conclusions
To our knowledge, these are the first reported in vivo rat cardiac $^{23}$Na MR images. The CSI sequence can be used to acquire one or several phases during the cardiac cycle as shown above, but also in the multi-slice mode to cover multiple slices through the heart. When used in combination with a $^{23}$Na shift reagent, the sequence potentially allows for discrimination of intra- and extracellular Na signals, because the frequency information is preserved as opposed to other types of MRI sequences like ultra-short TE. This method offers a new tool for studying myocardial ion homeostasis in vivo and may be of interest for different areas of cardiovascular disease, e.g. myocardial infarction, myocardial hypertrophy, but could also be used to study other organs like kidney, liver or tumours.

Figure 1. ECG-triggered $^1$H (left), $^{23}$Na CSI (middle) and overlay (right) images of a rat heart.

Figure 2. Cine $^{23}$Na CSI of different phases during the cardiac cycle, 30 ms apart, overlaid on $^1$H images.